Assessment of Aquatic and Terrestrial Acid Precipitation Sensitivities for Ontario

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by

D.W. Cowell

ACID PRECIPITATION RESEARCH
APIOS Report 009/86
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Lands Directorate
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ABSTRACT

A 1:1 000 000 scale colour map of Ontario in two parts showing areas north and south of 48° N latitude and depicting 51 combinations of soil depth, soil chemistry (or surrogates) and bedrock lithology have been prepared to illustrate relative ecosystem sensitivity to acid precipitation. The map shows areas interpreted to have high, moderate or low potentials to reduce the acidity of atmospheric depositions. These "potentials" may be used to interpret regional surface water sensitivity to acid precipitation. The map also shows areas dominated by organic terrain which are not interpreted with respect to sensitivity. From this compilation, 23,1% (247 027 km^2) of Ontario is interpreted as non-sensitive to acid precipitation (i.e. has a high potential to reduce acidity); 18,0% (192 006 km^2) is moderately sensitive; and 31,4% (335 121 km^2) is highly sensitive (has a low potential to reduce acidity). A total of 336 231 km^2 (31,5%) of Ontario consists of highly or moderately sensitive areas that receive annual loadings of wet sulphate at levels considered sufficient to cause damage to aquatic ecosystems. An additional 27,6% of Ontario comprising organic terrain has not been rated in terms of potential to reduce acidity or sensitivity to acid precipitation.

Specific, potential terrestrial sensitivities (base cation loss, soil acidification, and Al^{3+} solubilization) and implications for forest productivity are also examined. These are based on a regrouping of the 51 terrain classes from the 1:1 000 000 base map into eight map units based predominately on soil texture and bedrock lithology.

RÉSUMÉ

On a établi une carte en couleurs de l'Ontario en deux parties, au 1:1 000 000, représentant les régions situées au nord et au sud de 48° de latitude Nord et comprenant 51 combinaisons de profondeur du sol, de sa composition chimique (ou substituts) et de composition de la roche en place afin d'illustrer la sensibilité relative des écosystèmes aux précipitations acides. La carte indique le potentiel des régions - élevé, modéré ou faible - de réduire l'acidité des retombées. Ces indications peuvent servir à déterminer la sensibilité des eaux de surface régionales aux précipitations acides. Cette carte indique aussi les endroits où les terrains organiques dominent. Ces derniers n'ont toutefois pas été répertoriés en fonction de leur sensibilité aux précipitations acides. De cette compilation, on constate que 23,1% (247 027 km de la superficie de l'Ontario est considérée comme étant insensible aux précipitations acides (c'est-à-dire qu'elle possède un potentiel élevé de réduire l'acidité); 18,0% (192 008 km^2) est modérément sensible et 31,4% (335 121 km^2) est très sensible (potentiel faible de réduire l'acidité). Au total, 336 231 km^2 (31,5%) de la superficie de l'Ontario est constituée de régions dont la sensibilité aux précipitations acides est élevée ou moyenne et qui reçoivent des concentrations annuelles de sulfates humides capables d'endommager les écosystèmes aquatiques. De plus, 27,6% de la superficie de l'Ontario est composée de terrains, organiques dont on n'a pas évalué la capacité de réduire l'acidité, ni la sensibilité aux précipitations acides.

Le rapport examine également des aspects spécifiques de la sensibilité terrestre potentielle (perte des cations basiques, acidification du sol et solubilisation des ions AL^{3+}) de même que les conséquences sur la productivité forestière. Pour obtenir ces renseignements, on a regroupé les 51 catégories de terrains provenant de la carte de base au 1:1 000 000 en huit groupes établis surtout selon la texture du sol et la composition de la roche en place.

ACKNOWLEDGEMENTS

The author would like to express his gratitude to the individuals who were involved in this effort. Mr. B. Hosler procured, reviewed, collated, and drafted the complex assembly and production requirements of the accompanying maps to this report. Mr. G. Bangay, formerly Ontario Regional Director of the Lands Directorate, Environment Canada, provided much needed support at critical times in his role as Canadian Co-Chairman of Working Group I on Impact Assessment, Canada - United States Memorandum of Intent on Transboundary Air Pollution.

Ms. A.E. Lucas shares responsibility for the conceptual design and criteria development for earlier versions of the accompanying maps and supervised the day to day map production. The revised compilation of the "potential to reduce acidity" map has been supervised by Mr. R. Sayer of the Lands Directorate and drafted by the K.G. Campbell Corporation, Ottawa and the Conservation and Protection Drafting Division of Environment Canada. The final text has been compiled by Mr. C.D.A. Rubec of the Lands Directorate, Environment Canada, and Ms. D.E. Corrigan and Dr. S.N. Linzon of the Air Resources Branch, Ontario Ministry of the Environment.

PREFACE

This report and accompanying map provide interpretations of acid precipitation sensitivity for Ontario based upon a nationally applied model for aquatic applications. The concept is based on discussions held at an international workshop on sensitivity mapping (Cowell et al. 1981). The background research leading to this document was initiated in 1980 in support of on-going Canada - United States Memorandum of Intent on Transboundary Air Pollution negotiations. Material previously published in the Memorandum of Intent (1983) for the southern portion of Ontario has been updated and revised in light of more recent data and verification through the Acid Precipitation in Ontario Studies (APIOS) Program of the Ontario Ministry of the Environment. Unpublished interpretations for northern Ontario have been added. The terrestrial interpretations are drawn from an unpublished paper and map (Cowell and Lucas 1983) prepared in 1983 for the Acid Rain and Forests Resources Conference held at Quebec, Quebec.

This report complements a series of comparable and parallel sensitivity interpretations for western, northern and eastern areas of Canada published from 1983-86 by Environment Canada and several other provincial and territorial agencies.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The concept of "acid precipitation sensitivity" can be confusing and misleading. There is no such thing as an overall sensitivity scheme which encompasses all possible effects. Differing properties of the ecosystem or different ecosystems can be impacted by the same pollutant in varying ways. For example, a soil having a relatively large base cation reserve may be highly sensitive to base cation leaching while being non-sensitive to aluminum solubility. Thus it is important to define the ecosystem or ecosystem property being considered with regard to sensitivity. For mapping purposes, it is preferable to identify key ecosystem properties, then infer sensitivities based on specific ecosystem components. Appropriate interpretations can then be made separately and upgraded as new evidence is obtained. This approach to sensitivity analysis has been applied to the Province of Ontario.

The map of Ontario accompanying this report represents the culmination of a series of maps which have been developed between 1980 and 1984. Earlier versions included all of eastern Canada (east of the Ontario - Manitoba boundary). They were produced at a variety of scales, generally becoming more detailed (larger scale) as improved information was obtained. The maps appeared in various forms within the reports of the Impact Assessment Work Group established under the United States - Canada Memorandum of Intent (Memorandum of Intent 1981; 1982; and 1983), as well as in other publications (Cowell _et al_. 1981; Cowell and Lucas 1983; and Lucas and Cowell 1984).

Emphasis, over time, changed from portraying specific sensitivities (i.e. on surface waters and forest productivity) toward compilation of a standardized data base of terrain characteristics. This approach results in greater flexibility and allows interpretations other than those applied by the author.

CRITERIA AND MAPPING METHODOLOGY

The accompanying 1:1 000 000 scale map in two parts for Ontario is based on naturally occurring combinations of bedrock lithology, soil

depth (including percent exposed bedrock) and petrography or soil texture. They are derived from several sources of mapped information (Figure 1, Table 1). Table 2 illustrates how each of the soil and bedrock factors were interpreted with regard to their potential to reduce the acidity of atmospheric deposition. According to Cowell et al. (1981), soil chemistry, or some combination of soil chemistry and texture, are preferred factors in sensitivity analysis. However, soil chemistry data including soil pH, exchangeable bases, and cation exchange capacity are not readily available for large areas of Ontario, particularly within the areas of the Canadian Shield. Hence, available surrogates such as petrography or soil texture have been employed.

Richards et al. (1979) have defined petrography (as utilized within the Ontario Land Inventory coverage, Figure 1) as "the mineral composition of soil particles. It gives an indication of mineral nutrients which are available to vegetation". Soil texture and depth to carbonate, as mapped in the Ontario Land Inventory (OLI), provide comparable interpretations in about 75% of the cases. Where they most commonly diverge is in the case of clay soils (high potential to reduce acidity) mapped as low lime (moderate potential). However, this was not considered serious.

Texture is a suitable surrogate for those areas where petrography information is not available or is insufficient alone for the interpretations produced (Figure 1, Table 1). It may even be the most useful variable overall because chemical and physical characteristics are related. Sandy soils generally have low CEC and exchangeable bases compared to clay soils which generally have high CEC and base cations. Also, sandy soils allow more rapid flow-through of percolating water which in turn minimizes contact with soil particles.

Lack of available information and excessive map complexity did not permit incorporation of vegetation, relief and drainage as recommended by Cowell et al. (1981). Their eventual incorporation would permit more integrated and holistic sensitivity interpretation of the ecosystem.

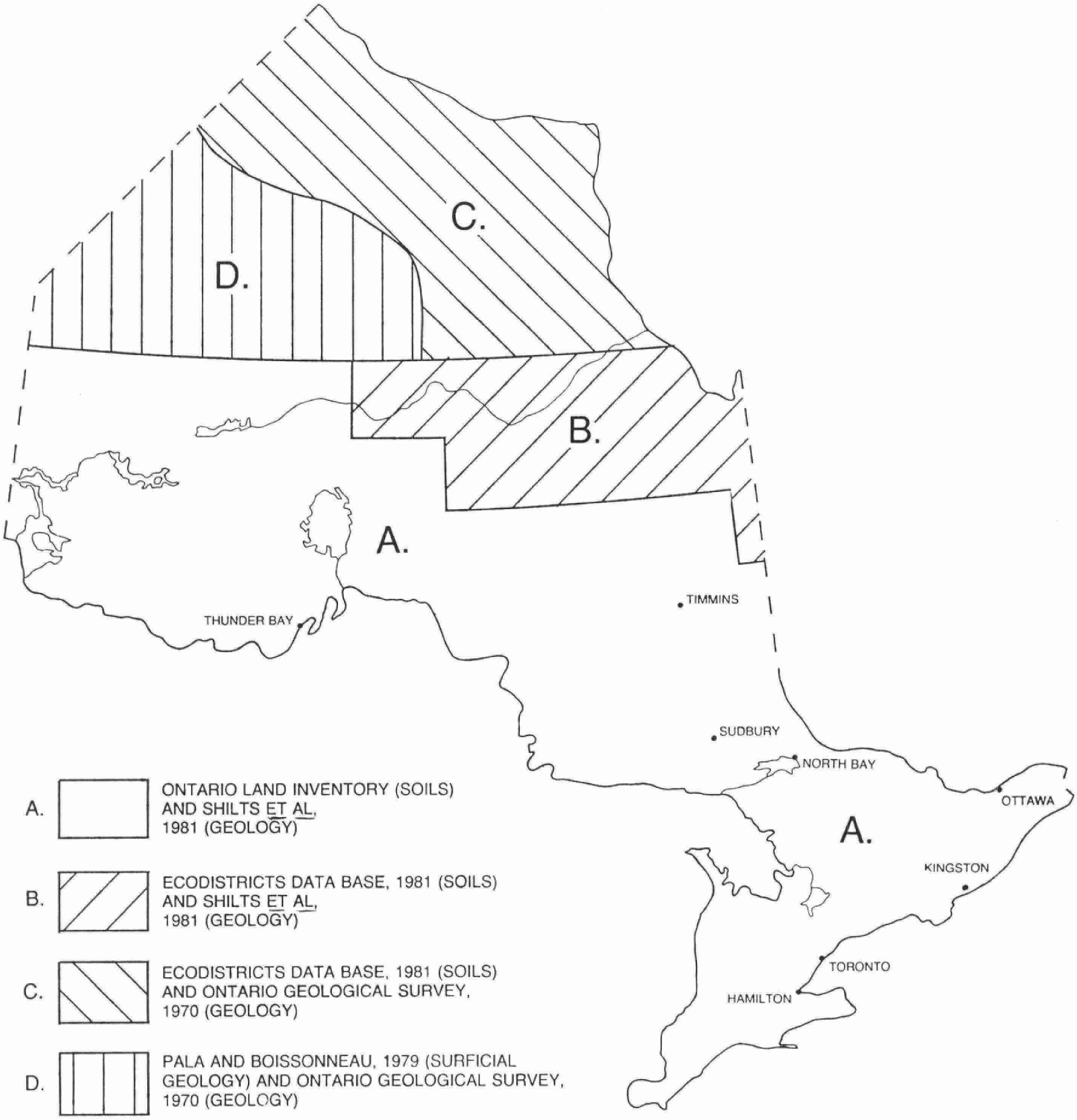


FIGURE 1: DATA SOURCES USED IN THE COMPILATION OF POTENTIAL OF SOILS AND BEDROCK TO REDUCE THE ACIDITY OF INCOMING ACIDIC DEPOSITION FOR ONTARIO MAP

TABLE 1: TERRESTRIAL FACTORS AND SOURCES FOR THE INTERPRETATION OF THE POTENTIAL TO REDUCE ACIDITY OF ATMOSPHERIC DEPOSITION IN ONTARIO

TERRESTRIAL CRITERIA AND CLASSES	COVERAGE (FROM FIGURE 1)	REFERENCE
Bedrock Geology		
High, Moderate, Low Sensitivity	A, B	Shilts *et al*. (1981)
Lithology	C, D	Ontario Geological Survey (1970)
Soil Depth		
Deep, Shallow, Very Shallow, Barren	A	Ontario Land Inventory (1977)
Deep, Shallow, Barren	B, C	Ecodistrict Data Base (1981)
Soil Chemistry Surrogates		
Texture (Clay, Loam, Sand)	B, C	Ecodistrict Data Base (1981)
Carbonate Content (High, Low, No Lime)	A	Ontario Land Inventory (1977)
Glacial Landforms	D	Pala and Boissonneau (1979)
Organic Soils (>50% Mapping Unit)	B, C, D	Wetlands Working Group (1981)

TABLE 2

TERRESTRIAL FACTORS AND ASSOCIATED CRITERIA FOR DETERMINING THE POTENTIAL OF TERRESTRIAL ECOSYSTEMS TO REDUCE THE ACIDITY OF ATMOSPHERIC DEPOSITION

	Potential to Reduce Acidity of Atmospheric Deposition		
Terrestrial Factors	High	Moderate	Low
Soil Chemistry			
Exchangeable Bases meq.100 g^{-1} Surrogates:	> 15	6-15	< 6
Family Particle Size and pH in Water	Clayey, pH 5.0; loamy, pH > 5.5; all calcareous soils	Clayey, pH 4.5-5.0; loamy, pH 5.0-5.5; sandy, pH > 5.5	Clayey, pH 4.5; loamy, pH < 5.0; sandy, pH<5.5
Texture	Clay, silty clay, sandy clay (> 35% clay)	Silty clay loam, clay loam, sandy clay loam, silt loam, loam (10 to 35% clay)	Silt, sandy loam, loamy sand, sand (10% clay)
Cation Exchange Capacity (meq.100 g^{-1})	25	10 to 25	< 10
SO_4^{2-} Adsorption Capacity	High sulphate adsorption, low organic matter, and high Al_2O_3 and/or Fe_2O_3+Fe_3O_4 content		Low sulphate adsorption, and high organic matter, and/or low Al_2O_3 and/or Fe_2O_3 + Fe_3O_4 contents
Soil Depth (cm)	> 100	25-100	< 25
Soil Drainage	Poor	Imperfect to well	Rapid
Landform Relief	Level	Rolling	Steep
Vegetation	Deciduous	Mixed	Coniferous
Vegetation Cover	Continuous (> 60%)	Discontinuous to sparse (20-60%)	Sparse to barren (< 20%)
Underlying Material			
Parent Material	Carbonate bearing	Noncarbonate bearing	Noncarbonate bearing
Bedrock Material	Limestone, dolomite, and metamorphic equivalents, calcareous clastic rocks, carbonate rocks interbedded with noncarbonate rocks	Volcanic rocks, shales, greywackes, sandstones, ultramafic rocks, gabbro, mudstone, metaequivalents	Granite, granite gneiss, orthoquartzite, syenite

Source: Cowell *et al.* (1981).

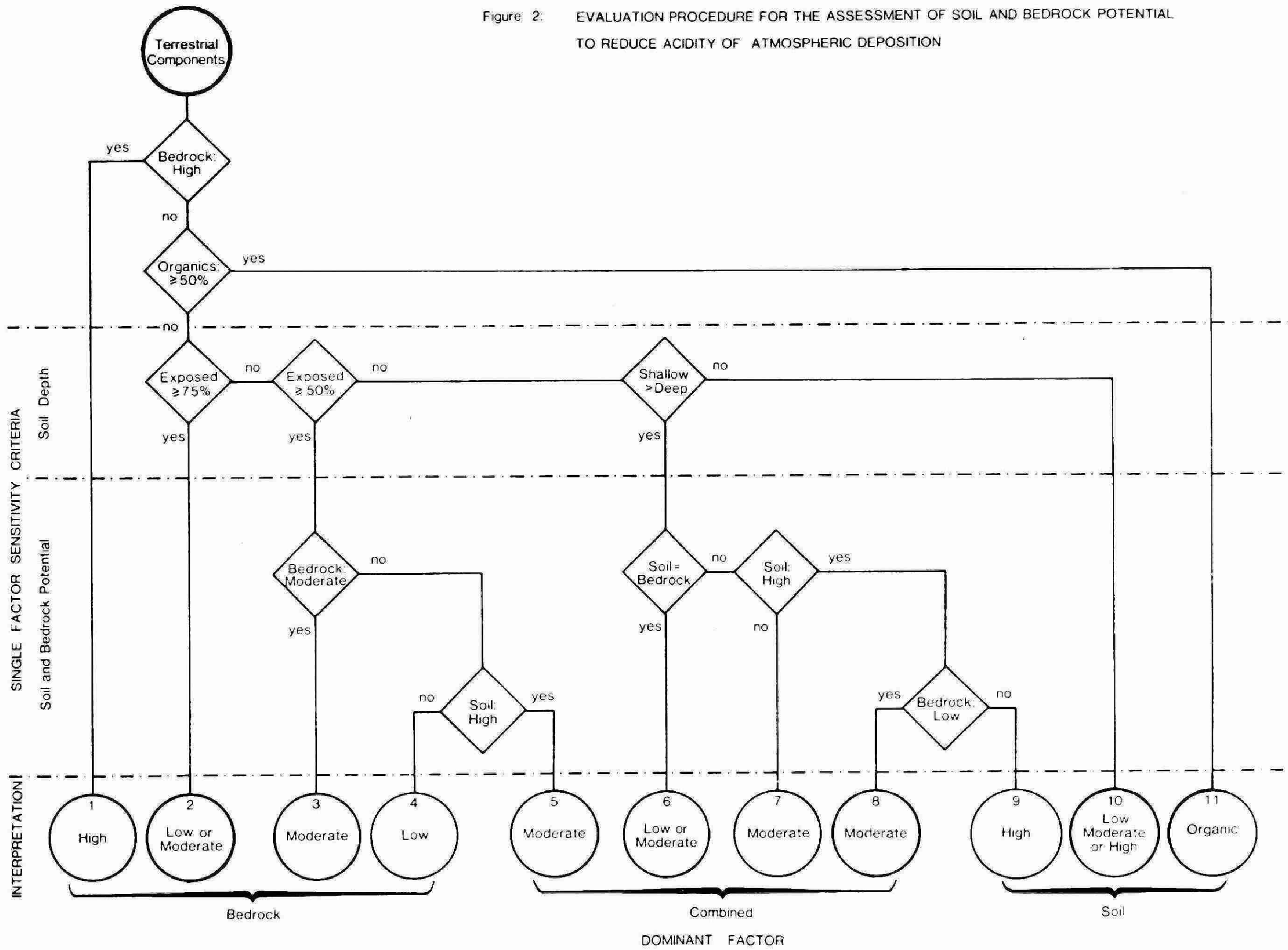
Within area A (Figure 1), OLI polygons formed the basic mapping unit. In the remainder of Ontario, map units were based on ecodistricts (areas B and C) and surficial geology (area D). To assign map units a high, moderate or low potential to reduce acidity, each of the factors (bedrock, soil depth, percent bedrock exposure and petrography or texture) was evaluated individually. The number of potential combinations is virtually unlimited when the percentage of deep and shallow soil and exposed bedrock is considered for each map unit. Thus, certain assumptions were made to standardize the decision-making process and minimize the number of possible combinations.

The flow diagram presented in Figure 2 illustrates the decision-making process. It is a conceptual framework based on inferred relationships between combinations of factors and the overall ability of the soils and bedrock in the map unit to reduce acidity. Altering the basic assumptions and boundary values (e.g. percentage bedrock exposure) would affect the final map product. Boundary values (50 and 75%) were assigned arbitrarily to produce a manageable number of classes; however, their significance has not yet been validated.

It is assumed that all drainage waters in carbonate-rich terrain contact bedrock or carbonate-rich glacial deposits (case 1 in Figure 2). Therefore, all areas underlain by limestone, dolomite or other carbonate-rich bedrock (Table 1) are assigned a high potential to reduce acidity, regardless of the overlying soil characteristics except where overlain by organic soils.

At this time it is not known to what degree wetlands and organic groundwater are affected by, or in turn modify, incoming anthropogenic mineral acids. These areas already contribute low pH, low-bicarbonate water to watersheds although some, such as those in the Hudson Bay Lowland, are perched on carbonate sediments and bedrock. Hence, no interpretation has been placed on areas dominated by organic soil and they have been mapped as 'organic' (case 11, Figure 2). The interrelationships between acid precipitation and wetland ecosystems have recently been reviewed by Anderson (1986) and through regional studies in Nova Scotia by Kessel-Taylor (1986).

Figure 2: EVALUATION PROCEDURE FOR THE ASSESSMENT OF SOIL AND BEDROCK POTENTIAL TO REDUCE ACIDITY OF ATMOSPHERIC DEPOSITION



Soil depth is used in the next stage of the interpretation. Where bedrock exposure equals or exceeds 50% of the map polygon, the emphasis is on the bedrock capacity to reduce acidity (cases 2, 3 and 4). Case 5, Figure 2, is an exception to this. The combination of deep or shallow soils of high potential overlying bedrock of low potential with 50-74% exposed is averaged and assigned a moderate potential. In this instance, it is assumed that although the soils can substantially reduce acidity they do not cover a sufficient area to warrant an overall assessment of high potential. This is countered by the low potential of the predominantly exposed bedrock.

Interpretation of map units dominated by shallow soils is based on the combined potentials of bedrock and soil characteristics (cases 6, 7 and 8). Where shallow soils of high potential overlie bedrock of moderate potential, the polygon is assigned an overall assessment of high potential to reduce acidity (case 9). Soil properties define the potential for all map units dominated by deep soils (case 10). Deep soils are identified as having greater than 1 m of unconsolidated material overlying bedrock.

The resulting map of Ontario (Figure 4), in two parts north and south of about 48 N latitude, consists of 51 differing map classes of bedrock geology, soil depth and petrography (texture). These in turn are grouped into moderate, high, or low potential interpretations of potential to reduce acidity as well as organic classes. These interpretations assist in organizing the map units with respect to varying properties relating to acidic deposition.

SENSITIVITY INTERPRETATIONS

a) Surface Water Sensitivity

The high, low, and moderate "potential to reduce acidity" classification of polygons (H, M, L) as indicated by the first identifier in the map legend (Table 3, Figure 4) can be directly related to an interpretation of surface water sensitivity.

For purposes of this analysis, areas having a low potential to reduce the acidity of atmospheric deposition are interpreted as having the most 'sensitive' aquatic systems. Conversely, areas having a high potential to reduce acidity are interpreted as having non-sensitive surface waters. Because soil and bedrock within watersheds interact with incoming precipitation which collects in streams and lakes, lake chemistry is assumed to reflect the geochemical make-up of surrounding watersheds. Simple basin flow conditions are also assumed and no direct consideration has been given to soil or rock groundwater residence times or deep groundwater contributions to lakes. However, these are partly a function of soil texture and depth such that the most sensitive aquatic systems are also the least likely to have significant groundwater inputs e.g. shallow sands overlying granite.

Comparative analysis between mapped units and classes of lake alkalinity in southcentral Ontario has generally supported this assumption. Based on a chi-squared test, the relationship between three sensitivity classes (L, M or H) and lake alkalinity classes was found to be significant at the 0.001 level (Lucas and Cowell 1984).

Table 3 is the legend from the "potential to reduce acidity" map (Figure 4). It lists combinations of soil depth, percentage bedrock exposure, bedrock lithology, and petrography derived using the flow-diagram in Figure 2. The areas of map units, grouped according to mean annual loadings of wet sulphate in precipitation (1980 data), are listed in Table 4.

Three relative classes of interpreted sensitivity and a separate class for map units dominated by organic terrain are provided. There is no implied or stated ranking of individual map units within potential to reduce acidity classes (e.g. H1a versus H3b). Clearly, however, some units will display greater or lesser potentials depending on weathering, vegetation composition and soil water flow characteristics.

The Province of Ontario is 1 068 587 km^2 in total area. The two columns to the far right on Table 4 provide area and percentage cover

TABLE 3

TERRESTRIAL CHARACTERISTICS OF AREAS IN ONTARIO HAVING HIGH, MODERATE AND LOW POTENTIAL TO REDUCE ACIDITY (AFTER LUCAS AND COWELL 1984)

	TERRAIN DESCRIPTION				
	Polygon Classification	Soil Depth[a]	Soil Texture[b]	Bedrock Class[c]	% Bedrock Outcropping[d]
HIGH POTENTIAL TO REDUCE ACIDITY	H1a	deep	clay	Type 1	0-49
	H1b	deep	loam	Type 1	0-49
	H1c	deep	sand	Type 1	0-49
	H1e	deep	loam	Type 1	50-99
	H1f	deep	sand	Type 1	50-99
	H1g	shallow	clay	Type 1	0-49
	H1h	shallow	loam	Type 1	0-49
	H1i	shallow	sand	Type 1	0-49
	H1j	shallow	clay, loam or sand	Type 1	50-99
	H2a	shallow	clay	Type 2	0-49
	H2b	shallow	clay	Type 3	0-49
	H3a	deep	clay	Type 2	0-49
	H3b	deep	clay	Type 3	0-49
	H3c	deep	clay	Type 4	0-49
MODERATE POTENTIAL TO REDUCE ACIDITY	M1d	deep	loam	Type 3	50-74
	M1p	shallow	loam	Type 3	50-74
	M1q	shallow	sand	Type 2	50-74
	M1r	shallow	sand	Type 3	50-74
	M1t	shallow	clay, loam or sand	Type 3	75-99
	M1v	bare	–	Type 3	100
	M2a	deep	clay	Type 4	50-74
	M2b	shallow	clay	Type 4	50-74
	M3	shallow	loam	Type 4	0-49
	M4a	shallow	sand	Type 2	0-49
	M4b	shallow	sand	Type 3	0-49
	M5	shallow	clay	Type 4	0-49
	M6a	shallow	loam	Type 2	0-49
	M6b	shallow	loam	Type 3	0-49
	M7a	deep	loam	Type 2	0-49
	M7b	deep	loam	Type 3	0-49
	M7c	deep	loam	Type 4	0-49

TABLE 3: CONTINUED

	TERRAIN DESCRIPTION				
	Polygon Classification	Soil Depth[a]	Soil Texture[b]	Bedrock Class[c]	% Bedrock Outcropping[d]
LOW POTENTIAL TO REDUCE ACIDITY	L1c	deep	sand	Type 4	75-99
	L1d	shallow	clay, loam or sand	Type 4	75-99
	L1e	bare	–	Type 4	100
	L2a	deep	loam	Type 4	50-74
	L2b	deep	sand	Type 4	50-74
	L2c	shallow	loam	Type 4	50-74
	L2d	shallow	sand	Type 4	50-74
	L3	shallow	sand	Type 4	0-49
	L4a	deep	sand	Type 2	0-49
	L4b	deep	sand	Type 3	0-49
	L4c	deep	sand	Type 4	0-49
ORGANIC TERRAIN[e]	01a		organics	Type 1	0-50
	01b		organics	Type 2	0-50
	01c		organics	Type 3	0-50
	01d		organics	Type 4	0-50
	02a		organics	Type 1	50-74
	02d		organics	Type 4	50-74
	03a		organics	Type 1	75-99
	03c		organics	Type 3	75-99
	03d		organics	Type 4	75-99

[a] Soil depth is defined as follows:

- deep - >1 m average soil thickness
- shallow - 25 cm - 1 m average soil thickness
- bare - <25 cm average soil thickness

[b] Soil texture is used to interpret soil sensitivity in Ontario where depth to carbonate information is not available. The following corresponding classes are used:

- clay - high or very high lime
- loam - moderate and low lime
- sand - low base or no lime

TABLE 3: CONTINUED

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[c] Bedrock sensitivity classes were defined by Shilts *et al*. (1981) on the basis of lithology. Specifically:

- Type 1 - Limestone, marble, dolomite.
- Type 2 - Carbonate-rich siliceous sedimentary: shale, limestone; noncalcareous siliceous with carbonate interbeds, shale, siltstone, dolomite, quartzose sandstone with carbonates.
- Type 3 - Ultramafic rocks, serpentine, noncalcareous siliceous sedimentary rocks, black shale, slate, chert, gabbro, anorthosite, diorite, basaltic and associated sedimentary mafic volcanic rocks.
- Type 4 - Granite, gneiss, quartzose sandstone, syenitic and associated alkalic rocks.

[d] Average bedrock outcropping within each map unit is shown as a percent of map unit.

[e] Organic materials are the dominant soil constituent wherever organics are indicated.

TABLE 4: DISTRIBUTION OF TERRAIN CLASSES IN ONTARIO BY INTERPRETED SENSITIVITY CLASS AND WET SULPHATE ZONE

Coverage of terrain types in Ontario interpreted for their potential to reduce acidity (H = high, M = moderate, L = low and O = organic terrain) and summarized by wet sulphate deposition regimes (Zone A = area of SO_4^{2-} in precipitation > 20 kg.ha^{-1}.yr^{-1}; Zone B = area between Zone A and 52°N Latitude - primarily 10-20 kg.ha^{-1}.yr^{-1} wet SO_4^{2-}; and Zone C = area north of 52°N Latitude - primarily receiving less than 10 kg.ha^{-1}.yr^{-1} wet SO_4^{2-}).

Ontario (Total Area = 1 068 587 km^2)

Terrain Class (Potential to Reduce Acidity)		Zone A (> 20 kg.ha^{-1}.yr)		Zone B (10-20 kg.ha^{-1}.yr^{-1})		Zone C (< 10 kg.ha^{-1}.yr^{-1})		Provincial Total	
		km^2	% of Zone	km^2	% of Zone	km^2	% of Zone	km^2	% of Province
1. High	H1a	27 907	11,19	7 519	1,67	35 258	9,54	70 684	6,62
	H1b	56 448	22,64	-	-	-	-	56 448	5,28
	H1c	665	0,27	-	-	-	-	665	0,06
	H1e	61	0,02	-	-	-	-	61	0,01
	H1f	109	0,04	-	-	-	-	109	0,01
	H1g	4 118	1,65	-	-	-	-	4 118	0,39
	H1h	1 261	0,51	-	-	-	-	1 261	0,12
	H1i	4 984	1,98	-	-	-	-	4 984	0,47
	H1j	641	0,26	-	-	-	-	641	0,06
	H2a	880	0,35	-	-	3 034	0,82	3 914	0,37
	H2b	20	0,01	-	-	2 230	0,60	2 250	0,21
	H3a	5 973	2,39	2 912	0,65	2 018	0,55	10 903	1,02
	H3b	4 861	1,95	21 941	4,88	1 964	0,53	28 766	2,69
	H3c	941	0,38	47 762	10,63	13 520	3,66	62 223	5,82
Total High Potential		108 869	43,66	80 134	17,83	58 024	15,69	247 027	23,12
2. Moderate	M1d	20	0,01	-	-	-	-	20	0,01
	M1p	-	-	68	0,02	566	0,15	634	0,06
	M1q	48	0,02	-	-	-	-	48	0,01
	M1r	252	0,10	440	0,10	-	-	692	0,07
	M1t	14	0,01	205	0,05	1 520	0,41	1 739	0,16
	M1v	-	-	-	-	14	0,00	14	0,00
	M2a	20	0,01	62	0,01	-	-	82	0,01
	M2b	109	0,04	873	0,19	-	-	982	0,09
	M3	811	0,33	7 275	1,62	46 726	12,64	54 812	5,13
	M4a	61	0,02	95	0,02	-	-	156	0,02
	M4b	16 248	6,52	17 836	3,97	-	-	34 084	3,19
	M5	423	0,17	6 314	1,40	6 027	1,63	12 764	1,20
	M6a	327	0,13	239	0,05	1 684	0,46	2 250	0,21
	M6b	34	0,01	1 786	0,40	5 523	1,49	7 343	0,69
	M7a	8 203	3,29	818	0,18	-	-	9 021	0,84
	M7b	3 961	1,59	9 608	2,14	2 420	0,65	15 989	1,50
	M7c	1 336	0,54	32 067	7,13	17 973	4,86	51 376	4,81
Total Moderate Potential		31 867	12,79	77 686	17,28	82 453	22,30	192 006	17,97
3. Low	L1c	102	0,04	41	0,01	-	-	143	0,01
	L1d	355	0,14	4 616	1,03	18 395	4,98	23 366	2,19
	L1e	82	0,03	130	0,03	730	0,20	942	0,09
	L2a	48	0,02	225	0,05	-	-	273	0,03
	L2b	136	0,05	389	0,09	-	-	525	0,05
	L2c	-	-	273	0,06	11 632	3,15	11 905	1,11
	L2d	1 595	0,64	10 242	2,28	-	-	11 837	1,11
	L3	63 310	25,39	93 765	20,86	-	-	157 075	14,70
	L4a	723	0,29	484	0,11	-	-	1 207	0,11
	L4b	8 092	3,25	21 102	4,69	-	-	29 194	2,73
	L4c	29 734	11,94	68 920	15,31	-	-	98 654	9,23
Total Low Potential		104 177	41,78	200 187	44,52	30 757	8,32	335 121	31,36
4. Organic Terrain	O1a	2 898	1,16	43 066	9,58	154 399	41,76	200 363	18,75
	O1b	259	0,10	12 888	2,87	23 414	6,33	36 561	3,42
	O1c	198	0,08	5 155	1,15	7 271	1,97	12 624	1,18
	O1d	470	0,19	30 389	6,76	13 392	3,62	44 251	4,14
	O2a	34	0,01	-	-	-	-	34	0,00
	O2d	170	0,07	-	-	-	-	170	0,02
	O3a	48	0,02	-	-	-	-	48	0,01
	O3c	55	0,02	-	-	-	-	55	0,01
	O3d	327	0,13	-	-	-	-	327	0,03
Total Organic		4 459	1,78	91 498	20,36	198 476	53,68	294 433	27,56
Total for Zone		249 372	100	449 505	100	369 710	100	1 068 587	100

for each map unit and potential to reduce acidity grouping on a province-wide basis.

For the Province as a whole, 23,1% (247 027 km^2) is classed as having a high potential to reduce acidity (generally having non-sensitive aquatic ecosystems in watersheds). Of the 14 map units making-up this class in Ontario, four types characterize over 90% of the variation. These are deep clays or loams over carbonate strata (units H1a and H1b), which dominate southern and southwestern Ontario; and deep clays over other lithologies (H3b and H3c) such as found in the Clay Belt of northeastern Ontario.

Moderately sensitive aquatic ecosystems are interpreted as occurring in 18,0% of Ontario (192 006 km^2). This class is dominated by four of its 1/ encompassing map units: (a) shallow or deep loams over sensitive bedrock (M3 and M/c); (b) shallow sands over moderately sensitive strata (M4b); and (c) deep loams over moderately sensitive strata (M7b). These are found widely distributed throughout central and northern Ontario and illustrate the terrestrial complexity of the Canadian Shield. It is not a simple massive area of highly sensitive soils and rocks as previously portrayed (Galloway and Cowling 19/8; Altschuller and McBean 1980). Map unit M3, which occupies 5,1% (54 812 km^2) of the total province, would likely possess the most sensitive watersheds of the four units noted. This is particularly true where it is found in association with a coniferous canopy under which podzolization processes have likely stripped much of the original base cation store. Underlying granite or other sensitive strata would not be expected to provide additional buffering.

The areas classed as having a low potential to reduce acidity (highly sensitive aquatic ecosystems) occupy 31,4% (335 121 km^2) of Ontario. This represents the largest grouping of classes and is also dominated by four of its 11 map units. These are: (a) shallow sands over sensitive bedrock (L3); (b) deep sands over moderate and sensitive strata (L4b and L4c); and (c) shallow mixed soils over sensitive bedrock (L1d). The L3 unit is by far the largest, occupying 14,7% of

Ontario (157 075 km^2). This unit is also, clearly, the most sensitive of all the non-organic map units and generally occurs within the zones receiving the greatest loadings of wet sulphate (Zones A and B, Table 4).

Organic terrain occupies 27,6% (294 433 km^2) of Ontario. The vast majority occurs north of 52°N latitude where annual acid sulphate loadings are consistently less than 10 $kg.ha^{-1}.yr^{-1}$. Most of these are peatlands which occur on the expansive Hudson Bay Lowland.

Approximately 23% of Ontario (249 372 km^2) receives 20 $kg.ha^{-1}.yr^{-1}$ or more of wet sulphate in precipitation (Zone A, Table 4). Empirical evidence suggests that wet sulphate deposition levels in excess of 20 $kg.ha^{-1}.yr^{-1}$ will cause damage to sensitive and moderately sensitive aquatic ecosystems (Memorandum of Intent 1983). As listed in Table 4, over half the area in Zone A (12.8% of Ontario - 136 044 km^2) is considered highly or moderately sensitive (having low or moderate potential to reduce acidity). This zone includes the Blind River to Sudbury and Muskoka-Haliburton regions which are densely covered with lakes.

Within the area of 10 to 20 $kg.ha^{-1}.yr^{-1}$ of wet sulphate in precipitation (Zone B, Table 4) there are approximately 200 187 km^2 (18,7% of Ontario) which are mapped as having a low potential to reduce acidity of precipitation (high sensitivity). Loadings of 10 to 20 $kg.ha^{-1}.yr^{-1}$ are believed to cause damage to highly sensitive lakes but not moderately sensitive lakes (Memorandum of Intent 1983).

Highly and moderately sensitive areas of Zone A and highly sensitive areas of Zone B comprise 336 231 km^2 (31,5%) of Ontario and are receiving loadings of wet sulphate in precipitation which are considered sufficient to cause damage to aquatic ecosystems (shaded area of Table 4). Within this area are an estimated 22 102 km^2 of surface water area (Memorandum of Intent 1983). It should be noted, however, that lakes represented in this estimate (or even lakes within

the same watershed) exhibit a range of actual impacts and water chemistry depending on forest cover, biological activity within lakes and other local site factors.

b) Terrestrial Sensitivity

The link between anthropogenic acidic deposition and effects on forest productivity is not well-defined. Although a cause-effect relationship has yet to be scientifically documented, circumstantial evidence is accumulating. Ulrich et al. (1980) have shown that in recent years, the decline of beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) has occurred in areas of West Germany receiving high inputs of hydrogen ion (H^+). This was attributed to sulphur dioxide (SO_2) emissions. Ulrich et al. have suggested that elevated aluminum ion (Al^{3+}) concentrations in the soil solution (the result of H^+ ion input to the soil body) is toxic to the fine roots of these trees. More recently, several theories have been proposed by other researchers in North America and Europe as to mechanisms resulting in forest decline, including synergistic effects of ozone and acid precipitation. Consensus has not been reached as to any specific or single mechanism but air pollution including acid deposition is believed to be a key factor associated with the observed declines.

There are numerous mechanisms by which anthropogenic acid depositions might affect forest productivity. Soil acidification is a primary concern because it may have direct effects on roots as well as indirect effects via Al^{3+} toxicity, base cation loss, decreased phosphate availability, changes in decomposition and nitrogen status as related to changes in species diversity, and abundance of microorganisms (Aber et al. 1982; McFee and Cronan 1982). Changes in forest productivity may be triggered by any of these mechanisms, by climatic, biological, and environmental conditions, or by any combination of acidification mechanisms, climate, insects, disease, and site factors. Hence, it is extremely difficult to isolate cause and effect relationships between forest productivity and atmospheric acid deposition in natural ecosystems.

Terrestrial sensitivity has been defined in terms of forest productivity (Cowell _et al_. 1981) and in terms of soil acidification (Wiklander 1973/1974; 1980). In these cases, effects within the soil body were emphasized. Cowell _et al_. (1981) regarded low pH mineral soils as potentially the most sensitive with regard to forest productivity based on the fact that such soils already had the smallest reserve of nutrient cations. It is assumed that additional losses of nutrient cations, however small, would be significant with respect to forest productivity in these acid soil systems. This sensitivity assessment concentrated on the upper 25 cm of the soil profile where nutrient cycling is most efficient. Certain acid soils are known to actively adsorb SO_4^{2-}, thereby reducing cation mobilization. They are considered less sensitive than nonsulphate adsorbing soils (Johnson and Cole 1977; Singh _et al_. 1980).

The soil sensitivity concept suggested by Wiklander (1973/1974; 1980) predicted noncalcareous, moderately acid sandy soils (pH 5-6) with low cation exchange capacity (CEC) to be the most sensitive to acidification. Wiklander derived these criteria from laboratory studies in which he found that the cation displacing efficiency of H^+ was greatly diminished as base saturation and pH decreased. Thus, for a given H^+ input, very acid soils would yield fewer cations and are classed as less sensitive than moderately acid soils. Moderately acid soils with low cation exchange capacity (i.e. less buffering by exchange sites) would experience more rapid pH change than very acid soils with the same exchange capacity. This theory by Wiklander is supported by soil monitoring studies in Ontario. Soils were resampled in 1978 after an 18 year period since previous analyses. The results indicate that all podzolized, sandy soils with a pH below 5.0 in upper soil horizons have displayed no significant decrease in pH between 1960-1978. However, a non-podzolized soil with pH averaging 5.7 in the upper soil horizons displayed a pH decline to an average of 4.8 during the monitoring period (Linzon and Temple 1980). This concept of assessing soil acidification potential, in which the most sensitive soils are those experiencing the greatest change in their inherent properties, is specifically a soil sensitivity evaluation. No

cause-effect relationships with vegetative or aquatic systems are specified.

In 1980, the Ontario Ministry of Environment initiated soil sensitivity assessments throughout the Province to supply information for mapping of soil sensitivity to acid precipitation. A soil baseline study has been developed to compile a uniform and reliable data base of soil chemistry parameters. A variety of soils on different landforms were sampled and analyzed (Griffith et al. 1984). Similarly, a soil geochemistry program by the Lands Directorate of Environment Canada with field studies in the 1982-83 period, has provided extensive data on boreal forest soils in Ontario (Cowell et al. 1986). These two data sets have been used in sensitivity assessments.

From the baseline data, it has been observed that the majority of soils located on the Canadian Shield are naturally acidic and tend to be sensitive to Al^{3+} solubilization. Soils in the St. Lawrence lowlands are generally finer textured, deeper, and have higher cation exchange capacities with freely available carbonates resulting in their having good acid neutralizing properties.

Chemical and physical data from selected soil baseline sites and boreal soil geochemistry survey points have been applied to compare and validate the interpretations of potential to reduce acidity and overall sensitivity on the maps accompanying this report. These regional sensitivity interpretations, given the limitations of the 1:1 000 000 mapping scale, are strongly supported by the two major acid precipitation soil point survey data bases now in existence from federal and provincial sources in Ontario. Inclusions of soils with dissimilar characteristics occur but have not been mapped relative to more dominant regional characteristics. For example, soil depth and texture can vary extensively even within a site plot leading to significant variance in interpretations of potential to reduce acidity.

In Canada, especially on the Canadian Shield, soils are quite variable in thickness and are commonly thin to discontinuous. Forest growth in

such areas is dependent on the bedrock to provide both the substrate and the only "store" of nutrient cations. Figure 3 (in pocket) entitled "Terrain Characteristics of Ontario" shows combinations of soil and bedrock characteristics which may be interpreted with respect to terrestrial sensitivities. This map was derived by recombining the 51 terrain classes mapped on the 1:1 000 000 scale accompanying map into eight map units representing differing soil and soil/bedrock combinations which could easily be shown at the reduced scale reproduced here. These have in turn been grouped in five categories for ease of interpretation: (1) organic soils; (2) barren areas (/5% bedrock outcropping); (3) sandy soils; (4) loamy soils; and (5) clayey soils.

Table 5 describes the map units illustrated on Figure 3 and their corresponding bedrock types and soil textures. Two classes of sulphate adsorbing soils (C_2 and D_2) are listed for completeness. For each of the map units having $>$ 75% exposed bedrock, the soil pH and CEC combinations most likely to occur are shown. Hypothetical sensitivity interpretations with respect to base cation loss, soil acidification and Al^{3+} solubilization are provided for each map unit and set of predicted soil properties. These interpretations are meant only as a guide and may need to be modified as empirical data are obtained. The sensitivities are relative in terms of the magnitude of soil changes. For example, a slight change in pH of an acid soil (low sensitivity to acidification) may produce a significant increase in aluminum solubility (moderate-high sensitivity). Table 5 relates only to soil properties; forest productivity sensitivity is not interpreted or inferred.

A. Organic Soils

Organic soils dominate map units in northern Ontario. It is uncertain what effect, if any, acidic deposition has on these soils or their associated vegetation communities. In Table 5 they are interpreted on the basis of having high CEC and low pH. Sensitivities are shown as low to moderate for all three soil effects. This assumes the soils have low base cation and metal (Al^{3+}) contents.

TABLE 5: RELATIONSHIP OF MAP UNITS TO TERRESTRIAL AND SOIL SENSITIVITY FACTORS

MAP UNIT	BEDROCK TYPE	SOIL CATEGORY	PREDICTED SOIL PROPERTIES PH	CEC	SENSITIVITY TO BASE CATION LOSS	SOIL ACIDIFICATION	ALUMINUM SOLUBILIZATION
A	1,2,3 or 4	Organic	<5	High	Low-Moderate	Low	Low-Moderate
B	1				High	Low-Moderate	Low-Moderate
	2,3				High	High	Moderate
	4				Moderate	Low	High
C_1	1,2, or 3	Sand	> 5	Low	High	Low-Moderate	Low-Moderate
C_2	4	Sand	< 5	High	Moderate	Low	Moderate-High
			< 5	Low	Moderate	Low	High
C_2**	4	Sand	< 5	High	Low	Moderate	Moderate-High
			< 5	Low	Low	High	High
D_1	1,2 or 3	Loam	> 6	Low	High	Low-Moderate	Low-Moderate
			> 6	High	High	Low	Low
D_2	4	Loam	< 5	High	Moderate	Low	Moderate-High
			< 5	Low	Moderate	Low	High
			5-6	High	High	Moderate	Moderate
			5-6	Low	High	High	Moderate
D_2**	4	Loam	< 5	High	Low	Moderate	Moderate-High
			< 5	Low	Low	High	High
E_1	1,2 or 3	Clay	> 6	High	High	Low	Low
E_2	4	Clay	> 6	High	High	Low	Low

*Bedrock sensitivity classes were defined by Shilts et al. (1981) on the basis on lithology
- Type 1 - Limestone, marble, dolomite
- Type 2 - Carbonate-rich siliceous sedimentary: shale, limestone, noncalcareous siliceous with carbonate interbeds, shale, siltstone, dolomite, quartzose sandstone with carbonates.
- Type 3 - Ultramafic rocks, serpentine, noncalcareous siliceous sedimentary rocks, black shale, slate, chert, anorthosite, gabbro, diorite, basaltic and associated sedimentary, mafic volcanic rocks.
- Type 4 - Granite, gneiss, quartzose sandstone, syenitic and associated alkalic rocks.

**Sulphate adsorbing soils.

It should be noted that many organic deposits have peat and groundwater pH values in excess of 5. The organic soils in the Hudson Bay Lowland overlie predominantly carbonate bedrock. Large areas of minerotrophic peatlands are found in this region, especially in coastal areas (Sims et al. 1982). The peatlands of the Lowland, however, are of little economic interest with respect to forest resources.

B. Barren Areas

Barren areas do not form a significant class in Ontario being isolated to only scattered units in northern Ontario.

C. Sand or No Lime Soils

These soils (C_1 and C_2) occupy about half of Ontario and include some of the most commercially important forest areas. Sand overlying granite (C_2) forms the largest single class. According to Clayton et al. (1977) these areas have primarily Humo-Ferric Podzols, 'Rockland' ($\geq$ 60% exposed bedrock) and Dystric Brunisols. These soil subgroups (especially C_2 soils) have acidic surface horizons (pH < 5.5, and dominantly < 5.0). They are thus considered to have a low sensitivity to acidification, a moderate sensitivity to base cation loss, and a moderate to high sensitivity with respect to Al^{3+} solubilization. Some areas of C_1 soils, particularly those overlying carbonate bedrock, likely have a higher pH. These would have a high potential for base cation loss but only low to moderate potential to acidify or have increased aluminum mobility.

Boreal and northern temperate Podzols are characterized by the accumulation of organic matter and Fe and Al sesquioxides (Stobbe 1968). Although high Fe and Al content are properties known to enhance sulphate adsorption (Johnson and Cole 1977), high organic matter tends to block the adsorption process (Johnson and Henderson 1979). Low pH, high CEC Podzols in Ontario probably do not significantly adsorb sulphate because their CEC is primarily controlled by organic matter. This is supported by analyses of Podzols from the Turkey Lakes

Watershed of north-central Ontario (Cowell and Wickware 1983; Wickware and Cowell 1985).

D. Loam or Low Lime Soils

D_1 and D_2 soils are located primarily in northwestern and southwestern Ontario. They are mapped by Clayton et al. (1977) primarily as Podzolic and Brunisolic. These soils are considered to exhibit a wide range of soil properties from very acidic (in boreal areas) to basic (those overlying carbonates).

E. Clay or High Lime Soils

These are found in small areas of southern Ontario and in the Clay Belt of northeastern Ontario. They are interpreted as having a low sensitivity with respect to soil acidification and Al^{3+} solubilization. However, sensitivity to base cation loss is high. According to Clayton et al. (1977) these soils are primarily Gray Luvisols and Gleysols (clay-rich and/or under periodic or seasonal flooding).

c) Implications for Forest Productivity

The most sensitive areas in Ontario with respect to forest productivity are suggested to be those areas mapped as C_1, C_2 and D_2 (Figure 3). These soils are considered to have the greatest potential for Al^{3+} mobilization given that most acid Podzols and Brunisols in eastern Canada have the highest amounts of Fe and Al sesquioxides. As noted above, sulphate adsorption is not considered to play a significant role in these young glacial soils (Abrahamsen 1980). Table 5 indicates that these soils have low to moderate sensitivities to base cation loss. This is relative to expected higher losses in soils richer in base cations. Because the low pH soils are already impoverished in these nutrients, it is assumed that any additional loss would have serious consequences to forest productivity.

Although areas mapped as C_1, C_2 or D_2 are considered the most sensitive with respect to forest productivity, they are not equally susceptible throughout the map area. Effects depend on the combination and total amount of acids received and hence the most susceptible forest areas are those mapped as C_1, C_2 or D_2 in areas receiving the highest acid loading. Generally, these loadings increase towards the south and southwest in Ontario (Memorandum of Intent 1983). It is not known at this time what loading regimes will produce negative effects to forest productivity.

SUMMARY

1. It is preferred, at this time, to map key ecosystem properties and infer sensitivities based on specific ecosystem components.

2. Soil depth and texture are useful surrogates for inferring regional sensitivity and are more widely available than soil chemistry data.

3. Soil depth is particularly critical in sensitivity analysis and for understanding aquatic-terrestrial linkages for regions within the recent glacial maxima. The upper 75 to 100 cm of such soils are strongly weathered leaving little or no basic cation store available for buffering. Deeper portions of the deposits are essentially unweathered and represent a distinct geochemical compartment with an abrupt increase in soil pH at the BC/C soil horizons boundary.

4. The Canadian Shield is a complex area consisting of a variety of bedrock lithologies, soil depths, soil petrography, and soil texture resulting in significant areas which range from non-sensitive to highly sensitive.

5. Areas having a low potential to reduce acidity are interpreted as having highly sensitive aquatic ecosystems. These comprise the largest sensitivity class, covering 31,4% (335 121 km^2) of Ontario.

6. Approximately 336 231 km^2 of Ontario (31,5%) are interpreted as either highly or moderately sensitive and receive annual loadings in excess of 10 $kg.ha^{-1}.yr^{-1}$ of wet sulphate which is believed to be sufficient to cause damage to aquatic ecosystems. There are estimated to be in the order of 22 102 km^2 of surface water area within this class. All of these surface waters do not necessarily have equivalent sensitivities due to local variability in bedrock, soil, vegetation and aquatic characteristics.

7. In examining terrestrial sensitivities it is important to distinguish among direct effects on soils, direct effects on vegetation, and indirect effects on vegetation via changes in the soil substrate.

8. Soil properties may give an indication of possible impacts of acid precipitation on terrestrial ecosystems through base cation loss, soil acidification, Al^{3+} mobilization, and, indirectly, forest productivity.

9. High organic matter contents common to boreal and northern temperate (poorly weathered, glaciated) soils restricts sulphate adsorption properties.

10. Areas with sandy-textured soils overlying sensitive bedrock types (C_1 and C_2, Table 5 and Figure 3) and with loamy soils overlying sensitive strata (D_2) are considered the most sensitive with respect to forest productivity.

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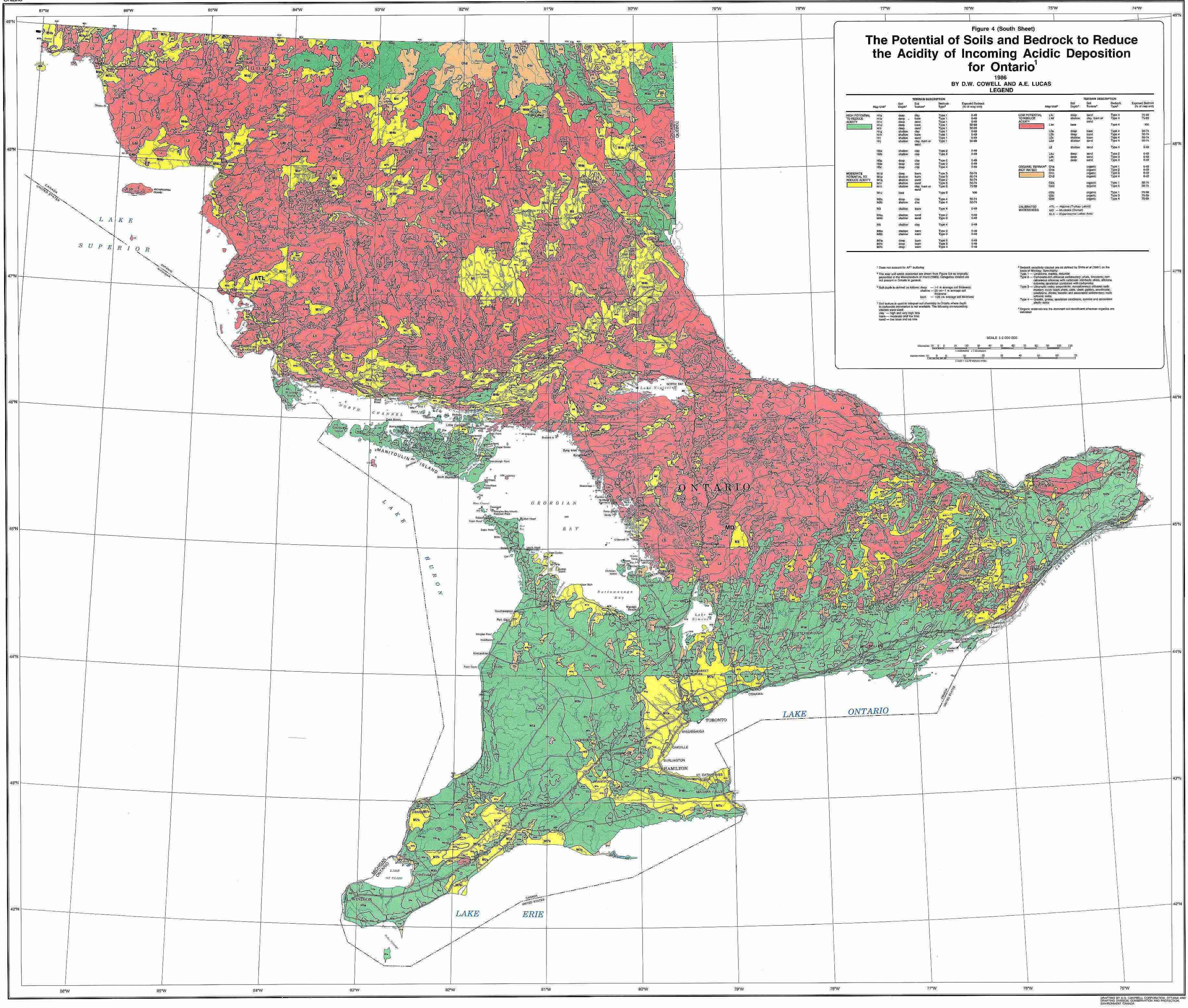

Figure 4 (South Sheet)

The Potential of Soils and Bedrock to Reduce the Acidity of Incoming Acidic Deposition for Ontario[1]

1986

BY D.W. COWELL AND A.E. LUCAS

LEGEND

	Map Unit[2]	Soil Depth[3]	Soil Texture[4]	Bedrock Type[5]	Exposed Bedrock (% of map unit)
HIGH POTENTIAL TO REDUCE ACIDITY	H1a	deep	clay	Type 1	0-49
	H1b	deep	loam	Type 1	0-49
	H1c	deep	sand	Type 1	0-49
	H1e	deep	loam	Type 1	50-99
	H1f	deep	sand	Type 1	50-99
	H1g	shallow	clay	Type 1	0-49
	H1h	shallow	loam	Type 1	0-49
	H1i	shallow	sand	Type 1	0-49
	H1j	shallow	clay, loam or sand	Type 1	50-99
	H2a	shallow	clay	Type 2	0-49
	H2b	shallow	clay	Type 3	0-49
	H3a	deep	clay	Type 2	0-49
	H3b	deep	clay	Type 3	0-49
	H3c	deep	clay	Type 4	0-49
MODERATE POTENTIAL TO REDUCE ACIDITY	M1d	deep	loam	Type 3	50-74
	M1p	shallow	loam	Type 3	50-74
	M1q	shallow	sand	Type 2	50-74
	M1r	shallow	sand	Type 3	50-74
	M1t	shallow	clay, loam or sand	Type 3	75-99
	M1v	bare		Type 3	100
	M2a	deep	clay	Type 4	50-74
	M2b	shallow	clay	Type 4	50-74
	M3	shallow	loam	Type 4	0-49
	M4a	shallow	sand	Type 2	0-49
	M4b	shallow	sand	Type 3	0-49
	M5	shallow	clay	Type 4	0-49
	M6a	shallow	loam	Type 2	0-49
	M6b	shallow	loam	Type 3	0-49
	M7a	deep	loam	Type 2	0-49
	M7b	deep	loam	Type 3	0-49
	M7c	deep	loam	Type 4	0-49

	Map Unit[2]	Soil Depth[3]	Soil Texture[4]	Bedrock Type[5]	Exposed Bedrock (% of map unit)
LOW POTENTIAL TO REDUCE ACIDITY	L1c	deep	sand	Type 4	75-99
	L1d	shallow	clay, loam or sand	Type 4	75-99
	L1e	bare		Type 4	100
	L2a	deep	loam	Type 4	50-74
	L2b	deep	sand	Type 4	50-74
	L2c	shallow	loam	Type 4	50-74
	L2d	shallow	sand	Type 4	50-74
	L3	shallow	sand	Type 4	0-49
	L4a	deep	sand	Type 2	0-49
	L4b	deep	sand	Type 3	0-49
	L4c	deep	sand	Type 4	0-49
ORGANIC TERRAIN[6] (NOT RATED)	O1a		organic	Type 1	0-49
	O1b		organic	Type 2	0-49
	O1c		organic	Type 3	0-49
	O1d		organic	Type 4	0-49
	O2a		organic	Type 1	50-74
	O2d		organic	Type 4	50-74
	O3a		organic	Type 1	75-99
	O3c		organic	Type 3	75-99
	O3d		organic	Type 4	75-99

CALIBRATED WATERSHEDS
ATL — Algoma (Turkey Lakes)
MD — Muskoka (Dorset)
ELA — Experimental Lakes Area

[1] Does not account for Al^{3+} buffering

[2] The map unit codes presented are drawn from Figure 3.9 as originally presented in the Memorandum of Intent (1983). Categories deleted are not present in Ontario in general.

[3] Soil depth is defined as follows: deep — >1 m average soil thickness; shallow — 25 cm–1 m average soil thickness; bare — <25 cm average soil thickness

[4] Soil texture is used to interpret soil chemistry in Ontario where depth to carbonate information is not available. The following corresponding classes were used:
clay — high and very high lime
loam — moderate and low lime
sand — low base and no lime

[5] Bedrock sensitivity classes are as defined by Shilts et al (1981) on the basis of lithology. Specifically:
Type 1 — Limestone, marble, dolomite
Type 2 — Carbonate-rich siliceous sedimentary: shale, limestone; non-calcareous siliceous with carbonate interbeds: shale, siltstone, dolomite; quartzose sandstone with carbonates
Type 3 — Ultramafic rocks: serpentinite; noncalcareous siliceous sedimentary rocks: black shale, slate, chert; gabbro, anorthosite, sandstone, diorite; basaltic and associated sedimentary; mafic volcanic rocks
Type 4 — Granite, gneiss, quartzose sandstone, syenitic and associated alkalic rocks

[6] Organic materials are the dominant soil constituent wherever organics are indicated

SCALE 1:1 000 000

kilometres 10 5 0 10 20 30 40 50 60 70 80 90 100 110
1 millimetre = 1 kilometre

statute miles 10 5 0 10 20 30 40 50 60 70
1 inch = 15.78 statute miles

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Ontario Ministry of the Environment

Hon. Jim Bradley
Minister

Rod McLeod
Deputy Minister

Canada

Environment Canada | Environnement Canada
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